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Urine sodium excretion increased slightly among U.S. adults between 1988–2010[1,2,3]

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Abstract

Little information is available on temporal trends in sodium intake in the U.S. population using urine sodium excretion as a biomarker. Our aim was to assess 1988–2010 trends in estimated 24-h urine sodium (24hUNa) excretion among U.S. adults (20–59 y) participating in the cross-sectional National Health and Nutrition Examination Survey (NHANES). We used subsamples from a 1988–1994 convenience sample, a 2003–2006 1/3 random sample, and a 2010 1/3 random sample to comply with resource constraints. We estimated 24hUNa excretion from measured sodium concentrations in spot urine samples by use of calibration equations (for men and women) derived from the INTERSALT study. Estimated 24hUNa excretion increased over the 20-y period (1988–1994, 2003–2006, and 2010) [mean ± SEM (*n*)]: 3160 ± 38.4 mg/d (1249), 3290 ± 29.4 mg/d (1235), and 3290 ± 44.4 mg/d (525), respectively (P_{trend} = 0.022). We observed significantly higher mean estimated 24hUNa excretion in each survey period (P <0.001) for men compared to women (31–33%) and for persons with higher body mass index (BMI) (32–35% for obese vs. normal weight) or blood pressure (–26% for hypertensive vs. normal blood pressure). After adjusting for age, sex, and race-ethnicity, temporal trends in mean estimated 24hUNa excretion remained statistically significant (P_{trend} = 0.004). We observed no temporal trends in mean estimated 24hUNa excretion among BMI subgroups, nor after adjusting for BMI. While several limitations apply to this analysis (the use of a convenience sample in 1988–1994 and using estimated 24hUNa excretion as a biomarker of sodium intake), these first NHANES data suggest

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[3]Supplemental Tables 1–6, Supplemental Figures 1–3, and Supplemental Methods 1 are available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at http://jn.nutrition.org.

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that mean estimated 24hUNa excretion increased slightly in U.S. adults over the last 2 decades and this increase may be explained by a shift in the distribution of BMI.

INTRODUCTION

The U.S. population consumes too much sodium, even though governmental agencies and professional health organizations continue to recommend reducing sodium intake to lower the risk of hypertension and cardiovascular disease (1–3). Estimates from What We Eat in America show that the U.S. population aged ≥2 y consumed on average 3463 mg/d of sodium from food and beverages in 2009–2010 (4), which is substantially higher than the *Healthy People 2020* objective of 2300 mg/d of sodium from all sources (5), the Institute of Medicine recommended tolerable upper intake level for adults of 2300 mg/d (2), the recommended limits in *Dietary Guidelines for* Americans of <2300 mg/d (1500 mg/d for specific subpopulations) (3), and the American Heart Association recommendation of ≤1500 mg/d (1).

Based on historic dietary data, mean sodium intake in the U.S. population increased among all age groups between NHANES I (1971–1974) and III (1988–1994), but seemed to level off between NHANES III, 1999–2000 (2,6), and 2003–2008 (7). In contrast, an analysis of sodium intake estimated from 24-h urine collections in 38 studies conducted in the United States, suggested no significant temporal trends in sodium intake between 1957 and 2003 (8). Although a recent study suggests the current dietary intake methods used in NHANES are valid for estimating population sodium intake among healthy, weight stable adults aged 30–69 y (9), dietary assessment and food coding methods changed somewhat over time, which may partially explain the discrepancy in results. Another potential explanation is that the studies assessing sodium using 24-h urine collections were not nationally representative.

The Institute of Medicine in their report on strategies to reduce sodium intake in the United States recommended exploring the use of stored urine samples for monitoring trends in U.S. sodium intake (10). The analysis of urine collected during a 24-h period reflects about 90% of the ingested sodium when complete and is considered to be an accurate and reliable measure of sodium intake (2). Because 24-h urine collections are challenging (11), burdensome for the participant, and could negatively affect the quality of the samples and the response rate to other NHANES components, the survey historically only collected a “casual” (random) urine sample, also called “spot” urine. These samples were used to assess environmental analytes and measure trace elements including iodine, but sodium was not assessed. While spot samples are not likely to provide a desirable level of accuracy for the purposes of estimating individual intake (12), a recent study suggests spot urine samples may be used to estimate average sodium intake among Western (North American and European) adults aged 20–59 y (13).

To generate the first nationally representative data on temporal trends in sodium intake in U.S. adults using estimated 24-h urine sodium (24hUNa)[7] excretion as a biomarker, we

[7]Abbreviations used: 24hUNa, 24-h urine sodium; BP, blood pressure; MEC, Mobile Examination Center; NCHS, National Center for Health Statistics.

measured sodium in selected surplus urine spot samples from 3 NHANES survey periods (1988–1994, 2003–2006, and 2010). We applied the newly available calibration equations derived from the Western INTERSALT study (13) to these data to generate estimated 24hUNa excretion. Here we describe the temporal trends over 2 decades in sodium excretion by demographic and health characteristics and compare estimated 24-h sodium excretion from spot urine with dietary sodium intake.

SUBJECTS AND METHODS

The NHANES has been collecting cross-sectional data on the health and nutritional status of the U.S. population first as periodic surveys (early 1970s to middle 1990s), and since 1999 as a continuous survey conducted in 2-y survey periods (14). The survey, designed and carried out by the National Center for Health Statistics (NCHS) at the Centers for Disease Control and Prevention (CDC), has a stratified, multistage, probability sample design and is representative of the civilian, non-institutionalized U.S. population. The NHANES combines home interviews with health tests performed in a Mobile Examination Center (MEC), where biologic samples are collected for biochemical analyses. All respondents gave their informed consent, and the NHANES protocol was approved by the NCHS Research Ethics Review Board.

Study design

The current cross-sectional study is based on a surplus sample proposal approved by NCHS to measure urine sodium in randomly selected spot urine samples from 3 NHANES survey periods: 1988–1994, 2003–2006, and 2010 (limited to 1 y due to resource constraints). Information on the urine samples used in this study is provided in Supplemental Methods 1.

Sample selection and exclusion criteria

The unweighted examination response rates for the overall sample (and for ages 20–59 y) were 78% (73%) for 1988–1994, 77% (73%) for 2003–2006, and 77% (77%) for 2010 (15). To optimize resources, we randomly sampled NHANES participants for laboratory analyses, selecting among participants who provided informed consent for further testing of stored samples and had non-missing data on urine creatinine concentration and dietary sodium intake. In addition, we applied exclusion criteria that may affect urine sodium excretion: pregnant women, participants who reported taking BP medications, angiotensin converting enzyme inhibitors or angiotensin II inhibitors, or a diuretic. We did not a priori exclude participants with severe renal disease (stages 3–5) because this would have negatively affected the sample size of participants with hypertension. We limited the first 2 survey periods (NHANES 1988–1994 and 2003–2006) to the adult population aged 20–59 y because this was the only age range for which we had urine samples in NHANES III and because older persons are more likely to have chronic conditions that could affect urine sodium excretion. Sample selection was based on BP and dietary sodium intake to ensure a wide range of values for these 2 related measures. All untreated hypertensive participants that fit the above criteria were included. The group of non-hypertensive participants was stratified into 8 groups based on their BP category (normal or pre-hypertension) and sodium intake quartile from 1 dietary recall. Participants were then randomly selected with

approximately equal numbers per strata. We selected 1249 participants from 1992 samples that met our criteria in NHANES 1988–1994 (Supplemental Fig. 1) (16). We selected 1241 participants in NHANES 2003–2006: 853 non-hypertensive participants from a 1/3 urine random subsample and 388 participants with hypertension from the full examination sample (Supplemental Fig. 2) (17). For NHANES 2010 we selected 525 persons 20–59 y old that met our criteria from a 1/3 urine random subsample (Supplemental Fig. 3) (18).

Laboratory methods

Urine sodium was measured at the CDC laboratory via ion-selective electrode (ISE) using the Cobas ISE/Na^+, K^+, Cl^- assay performed on the Roche Modular P instrument (Roche Diagnostics Corporation, Indianapolis, IN) (19). The CV measured in 4 urine quality control pools (56.6–169 mmol/L) were <2.5% (n = 144 runs). The assay performance is described in more detail elsewhere ([16–18]; Supplemental Methods 1).

Estimation of 24-h urine sodium excretion from spot samples

We used previously published calibration equations derived from the Western INTERSALT study (13) to predict 24hUNa excretion from spot urine sodium concentrations (Supplemental Methods 1). The equations were derived from 2841 male and 2852 female North American and European adults aged 20–59 y covering a low to high 24hUNa excretion group mean of 3386–5520 and 2709–3852 mg, respectively. They differed by sex and contained spot sodium, potassium, and creatinine concentrations as well as age and BMI.

Dietary sodium intake

Data on sodium intake from the diet were assessed using 24-h dietary recalls (Supplemental Methods 1). In NHANES 1988–1994, each participant had 1 24-h dietary recall administered in person at the MEC (about 5% of participants had a second recall administered by telephone 3–10 d later). In NHANES 2003–2006 and NHANES 2010, each participant had 2 24-h dietary recalls. We used the sodium intake information from the first recall as it was close in time to the MEC-provided spot urine sample.

Covariates

We categorized the covariates as follows: age (20–39 y and 40–59 y); race-ethnicity (non-Hispanic white [NHW], non-Hispanic black [NHB], and Mexican American [MA]; other racial-ethnic groups were included in overall estimates but not separately); BMI (normal [18.5–<25], overweight [25–<30], and obese [≥30] kg/m^2; underweight persons were included in overall estimates but not separately; [20]); BP (normal [SBP <120, DBP <80], prehypertension [SBP 120–139 or DBP 80–89], and hypertension [SBP ≥140 or DBP ≥90] mm Hg; [21]).

Statistical analyses

Statistical analyses were performed using SAS (version 9.3, SAS Institute Inc., Cary, NC) and SUDAAN (version 11, RTI, Research Triangle Park, NC) software. The specialized SUDAAN software considered the complex survey design by incorporating the survey

weights to account for the unequal probabilities of selection and adjustment for non-response. The NHANES 1988–1994 urine samples were a convenience sample of NHANES examinees (16), which cannot be assumed to be representative of the U.S. population. We made several attempts to address this limitation. We verified that the unweighted frequency distributions for age, sex and race-ethnicity compared for adults 20–59 y of age in the full NHANES sample, the full convenience sample, and our study sample (data not shown). The participant's choice to volunteer for the convenience sample was made without any knowledge of their urine sodium value and participant selection was at about equal rate from each location throughout the NHANES 1988–1994. Given these conditions, we created new sample weights taking into account the subsampling strategy and post-stratifying them to the NHANES III examination weights (Supplemental Methods 1). We then confirmed that the weighted frequency distributions for demographic characteristics (age, sex, race-ethnicity) and the weighted means for other participant key characteristics (BMI, BP, dietary sodium intake, caloric intake and urine creatinine) did not differ between our study sample and the full NHANES sample (adults 20–59 y of age, pregnant women excluded) (Supplemental Table 1). The data from NHANES 2003–2006 (17) and NHANES 2010 (18) were subsamples of the full samples, therefore new sample weights were created that took into account the subsampling strategy and non-response to the urine collection. These sample weights were post-stratified to the respective original examination sample weights. The single year data from 2010 are nationally representative and are derived from a probability sample. We calculated variance estimates using the delete-1 jackknife method to allow combining data from the 3 survey periods (Supplemental Methods 1).

We excluded a few participants who had been randomly selected due to missing data (Supplemental Methods 1). The estimated 24hUNa excretion distribution was close to Gaussian, requiring no transformation. The dietary sodium intake distribution was transformed to normality using a logarithmic transformation. We plotted weighted frequency distribution curves of estimated 24hUNa excretion by survey period and by BMI. We assessed bivariate associations between mean estimated 24hUNa excretion and geometric mean dietary sodium intake and categories of age, sex, race-ethnicity, BMI, and BP for each NHANES survey period. We used the Wald F test to compare means across categories and a linear trend test to assess temporal trends within each variable category. Using survey period as a categorical variable, we found no significant interactions between survey period and the other independent variables in a multiple linear regression model. Thus, we did not stratify by survey period in subsequent analyses that evaluated whether adjusting for certain covariates had an effect on the bivariate associations (Wald F test to compare adjusted means across categories). The BMI distribution in U.S. adults has shifted towards the right between 1980 and 1999, with more recent data suggesting a leveling off of this trend (22), and BMI is correlated to energy and sodium intake (12). Thus, our main multivariate model 1 only controlled for the standard demographic covariates (age, sex, and race-ethnicity). However, we assessed results from model 2 in which we additionally controlled for BMI to provide further insight into the potential reasons for change in sodium excretion. Statistical significance was defined as $P < 0.05$. No adjustment was made for multiple comparisons.

To assess the association between sodium excretion (as a measure of recent intake) and sodium intake (from the 24-h period preceding the urine sample), we calculated Spearman correlation coefficients for spot urine concentration (mmol/L), creatinine corrected spot urine sodium concentration (mmol/g), and estimated 24hUNa excretion (mg/d) vs. usual dietary sodium intake (mg/d). We categorized individuals into quartiles of usual dietary sodium intake and calculated the mean estimated 24hUNa excretion for each intake quartile and NHANES survey period. The estimation of usual dietary sodium intake is described in Supplemental Methods 1.

To provide reference information for urine sodium excretion, we calculated the mean and selected percentiles (5^{th}, 50^{th}, and 95^{th}) for spot urine concentrations (mmol/L), creatinine corrected spot urine sodium concentrations (mmol/g), and estimated 24hUNa excretion (mg/d) by demographic and health characteristics. Values in the text are means (geometric means) ± SEM. All reported estimates had a relative SEM of ≤30% and were considered statistically reliable.

RESULTS

A description of the demographic and health characteristics of the study population assessed in this analysis showed that changes occurred in the distributions of age, race-ethnicity, BMI, and BP status, but not sex (Table 1). The distribution of estimated 24hUNa excretion varied slightly by survey period with a range of approximately 1000 to 7000 mg/d (Figure 1a) and shifted notably to higher values with higher BMI when all survey years were combined (Figure 1b).

For the 3 survey periods (1988–1994, 2003–2006, and 2010) the estimated 24hUNa excretions among adults aged 20–59 y were 3160 ± 38.4 mg/d, 3290 ± 29.4 mg/d, and 3290 ± 44.4 mg/d, respectively, (P_{trend} = 0.022, Table 2). Slight increases in estimated 24hUNa excretion from 1988–1994 to 2010 were statistically significant among persons 20–39 y old, men, women, and persons with normal BP. Among other age, race-ethnic, BMI, or BP subgroups we found no temporal trends in estimated 24hUNa excretion. Although estimated 24hUNa excretion among non-Hispanic black adults increased the most of all the subgroups examined, from 3260 mg/d in 1988–1994 to 3470 mg/d in 2010, the temporal trend was not statistically significant (P_{trend} = 0.06). Within each survey period, men had significantly higher estimated 24hUNa excretion compared with women (31–33%) and estimated 24hUNa excretion varied significantly by BMI (32–35% higher for obese vs. normal weight) and BP (17–26% higher for hypertensive vs. normal blood pressure) status. Within the first 2 survey periods, but not the last survey period, estimated 24hUNa excretion varied significantly by race-ethnic groups. During all 3 time periods, the highest estimated 24hUNa excretion was among obese participants and the lowest among women.

Dietary sodium intakes for the 3 survey periods appeared higher than the estimated 24hUNa excretion, the error in the mean was larger, and we found no temporal trend: 3280 ± 83.3 mg/d, 3270 ± 68.2 mg/d, and 3400 ± 87.6 mg/d, respectively (P_{trend} = 0.34, Table 3). However, we noted a statistically significant temporal increase in dietary sodium intake for women, obese and prehypertensive persons. As seen with the estimated 24hUNa excretion,

men had significantly higher dietary sodium intakes compared with women (33–56%) for each survey period. Dietary sodium intake did not vary significantly by the other demographic and health characteristics, except for race-ethnicity in 2003–2006 and BP in 2010.

After adjusting for age, sex, race-ethnicity and survey period (model 1), the estimated 24hUNa excretion was significantly different by age ($P = 0.004$), sex ($P < 0.001$), and race-ethnicity ($P < 0.001$) and we observed a small (142 mg/d) but significant ($P_{trend} = 0.004$) increase in estimated 24hUNa excretion over the 3 time periods: 3190, 3260, and 3330 mg/d (Table 4). Temporal trends in estimated 24hUNa excretion were also statistically significant after adjusting individually for age ($P_{trend} = 0.028$), sex ($P_{trend} < 0.001$), or BP status ($P_{trend} = 0.007$) (data not shown). The temporal trend was not statistically significant after adjusting for race-ethnicity ($P_{trend} = 0.053$) and we found no trend after adjusting for BMI ($P_{trend} = 0.65$) (data not shown). When we adjusted for BMI in addition to the demographic variables (model 2), we found no temporal trend in estimated 24hUNa excretion ($P_{trend} = 0.22$). The model 2 adjusted estimated 24hUNa excretion was statistically significant by sex, race-ethnicity, and BMI. The significant positive association between estimated 24hUNa excretion and BMI found in the bivariate analysis (Table 2) was therefore maintained after adjusting for demographic variables.

Regardless of the model, temporal trends in dietary sodium intake were not statistically significant ($P_{trend} = 0.07$ for model 1; $P_{trend} = 0.10$ for model 2; Table 4). The adjusted dietary sodium intake was significantly different by age, sex, and race-ethnicity, but not by BMI (model 2).

For each survey period, we found moderate statistically significant correlations between the estimated 24hUNa excretion and the dietary sodium intake ($r = 0.31$ [1988–1994], 0.35 [2003–2006], and 0.34 [2010]), but only weak significant correlations ($r \leq 0.2$) for the urine spot sodium concentration or the creatinine corrected urine spot sodium concentration (Supplemental Table 2). The estimated 24hUNa excretion increased linearly by quartile of usual sodium intake for each survey period (Q1–Q4: 2650–3700 [1988–1994], 2790–3770 [2003–2006], and 2710–3820 [2010]; Figure 2).

Means and selected percentiles of the measured urine sodium concentrations and the creatinine corrected values in spot samples for the 3 survey periods by demographic and health characteristics are presented in Supplemental Tables 3 and 4. Selected percentiles (5^{th}, 50^{th}, and 95^{th}) for estimated 24hUNa excretion provide information on the normal range of a single urine sample (Supplemental Table 5). While these data do not allow an interpretation of the population percentiles of sodium intake, they may be of interest to investigators who have similar spot urine data and would like to compare it to data for U.S. adults.

DISCUSSION

In 2010, estimates of sodium intake from estimated 24hUNa excretion (3290 mg/d, Table 2) or dietary sodium intake (3400 mg/d, Table 3), were well above recommended limits. From

1988–2010, estimated 24hUNa excretion increased slightly among U.S. adults aged 20–59 y participating in the cross-sectional NHANES before and after adjusting for age, sex, and race-ethnicity. Across all 3 time periods, estimated 24hUNa excretion was strongly and positively associated with being male vs. female and with higher BMI and BP. We found no temporal trends in estimated 24hUNa excretion among BMI subgroups or after adjusting for BMI. Mean dietary sodium intake was also strongly and positively associated with being male vs. female, but it was not associated with BMI and did not change over time.

It has been shown that underreporting of energy intake (and thereby sodium intake) is more common in persons with higher BMI (23). This may explain the lack of association we found between dietary sodium intake and BMI, while we observed a strong and positive association between the objectively measured urine biomarker and BMI. Information on sodium intake based on urine measures is limited (Supplemental Table 6). In 1985–1987, the INTERSALT study related sodium intake, as assessed by a single 24-h urine collection, to BP in more than 10000 men and women aged 20–59 y at 52 centers in 32 countries. Among the 4 centers in the United States, urine sodium levels (mg/d) ranged from 2232–4012 in men and from 2538–3035 in women (24). Approximately 10 y later (1997–1999), the INTERMAP study aimed to clarify the role of multiple dietary factors to BP among 4700 men and women ages 40–59 y in East Asian and Western countries. Sodium intake (mg/d), as determined by 2 timed 24-h urine collections, was 4202 in U.S. men and 3272 in U.S. women (25). The U.S. Coronary Artery Risk Development in Young Adults (CARDIA) study conducted 3 consecutive 24-h urine collections in 920 participants (half Caucasian and half African American) aged 25–37 y in 1990–1991. Urine sodium levels (mg/d) were 4430 and 4550 for African American and white men, respectively, and 3584 and 3612 for African American and white women, respectively (24). A recent study that assessed sodium and related micronutrient status from timed-spot and 24-h urine samples in young (18–39 y) U.S. adults, the 2011 CDC/NIH sodium calibration study, found mean 24hUNa excretion of 3540 mg/d for men and 3090 mg/d for women (26). These data on 24hUNa excretion are generally comparable or slightly higher compared with our findings using spot urine samples to estimate 24hUNa excretion (3670 and 2790 mg/d for men for women, respectively, model 1). This is expected, given a recent analysis of the aforementioned CDC/NIH study suggesting estimated 24hUNa excretion using the INTERSALT equations are slightly lower than measured 24hUNa excretion (27).

Recently, Bernstein and Willett published results on trends in 24-h urine sodium excretion from a systematic review of 38 U.S. studies, including some of those cited above, conducted between 1957–2003 (8). The authors found no change in mean sodium intake over this time period and estimated an overall mean (SE) 24hUNa excretion of 3526 (75) mg/d (3911 mg/d for males and 3084 mg/d for females). The British Food Safety Agency surveys conducted from 1984–2008 also arrived at a similar mean (SD) 24hUNa excretion of 3450 (161) mg/d (3894 mg/d for males and 2965 mg/d for females) (28). These 24-h urine sodium excretion levels are also quite comparable to our estimated levels and the small differences could be a result of different populations, sample types, or time period.

As was previously shown (8,24,25), we also found a strong association between estimated 24hUNa excretion and sex, with higher sodium excretion in men compared to women,

consistent through all 3 survey periods and after adjusting for covariates. We noted sodium excretion was strongly (Spearman *rho* ~0.5; data not shown) and positively associated with BMI before and after adjusting for demographic covariates. This may be related to the inclusion of BMI in the INTERSALT prediction equations, although others have shown 24hUNa excretion to be mildly correlated ($r = 0.20$) with BMI (12). Not surprisingly, given the shifts in BMI over the same time period (23), we observed no temporal trends in sodium excretion once we adjusted for BMI. Whether or not to adjust for BMI depends on the question at hand and has been debated before (29,30). Thus, we presented the trends with and without adjusting for BMI.

The correlations between the estimated 24hUNa excretion and the dietary sodium intake in our study (Spearman *rho* = 0.31–0.35 for the 3 survey periods) were comparable to other studies, particularly if one considers that they were derived from a single spot urine and a single 24-h dietary recall. Reported correlations between 24-h sodium excretion and sodium intake are between 0.3 and 0.75 (if multiple 24-h excretions are considered) (31). The correlation for the INTERMAP study was 0.42 (4 24-h dietary recalls and 2 timed 24-h urines) (32). As expected, we found an association between sodium excretion and intake with estimated 24hUNa excretion increasing linearly by quartile of sodium intake for each survey period.

One major limitation of our study is that the stored urine from the oldest time period (1988–1994) was a convenience rather than a probability NHANES sample. This presents the question whether the sample is representative of the U.S. population and how much confidence can be placed in the statistical testing for temporal trends. Participants in our study sample were selected throughout the entire 6-y period and did not differ from participants in the full NHANES 1988–1994 sample with regard to demographic characteristics or in the central tendency of key variables used in our study. We thus made the assumption that our study sample was reasonably representative of the civilian non-institutionalized U.S. population and we calculated new sample weights to better account for potential bias in the way this NHANES 1988–1994 study sample was selected. It is possible though that the estimates for 1988–1994 are not generalizable to the target population which could affect the observed trends.

While the use of spot urines is currently not recommended for monitoring individual or population sodium intake because of the large diurnal variation in sodium excretion (10) and may have decreased our ability to detect small differences, a recent study indicated spot urines may be of some use for monitoring population mean sodium intake (13). The calibration equations we used to estimate 24hUNa excretion were derived from and validated in the Western INTERSALT study (13) and also recently validated in U.S. men and women (50% African-American) aged 18–39 y (27). However, the INTERSALT equation has not been externally validated among the NHANES population, nor among adults aged 40 y and older. A minor limitation of our study is that we were not able to account for within-person variability, which has been shown to be important even with the use of 24-h urine collections, particularly to accurately estimate population percentiles (33,34), because the participants in our study were sampled only once.

Our study has several strengths. It included a large sample of racial and ethnically diverse groups of adults from across the U.S. and used weighted data to generate estimates that are representative of the U.S. population. However, we applied certain exclusion criteria that may affect the generalizability of our findings. The analysis was stratified by various demographic and health characteristics, showing first time temporal trends in sodium intake in the U.S. population based on a urine sodium measure. While the results are limited to adults 20–59 y of age and several limitations apply to the data because they were derived from spot urine, these are the only available historic data, as no 24-h urine samples were collected in previous NHANES surveys. In summary, we conclude that increases in sodium intake among U.S. adults over the last 2 decades are small and may be associated with the shift in distribution of BMI. Sodium intake among U.S. adults remains higher than recommended levels.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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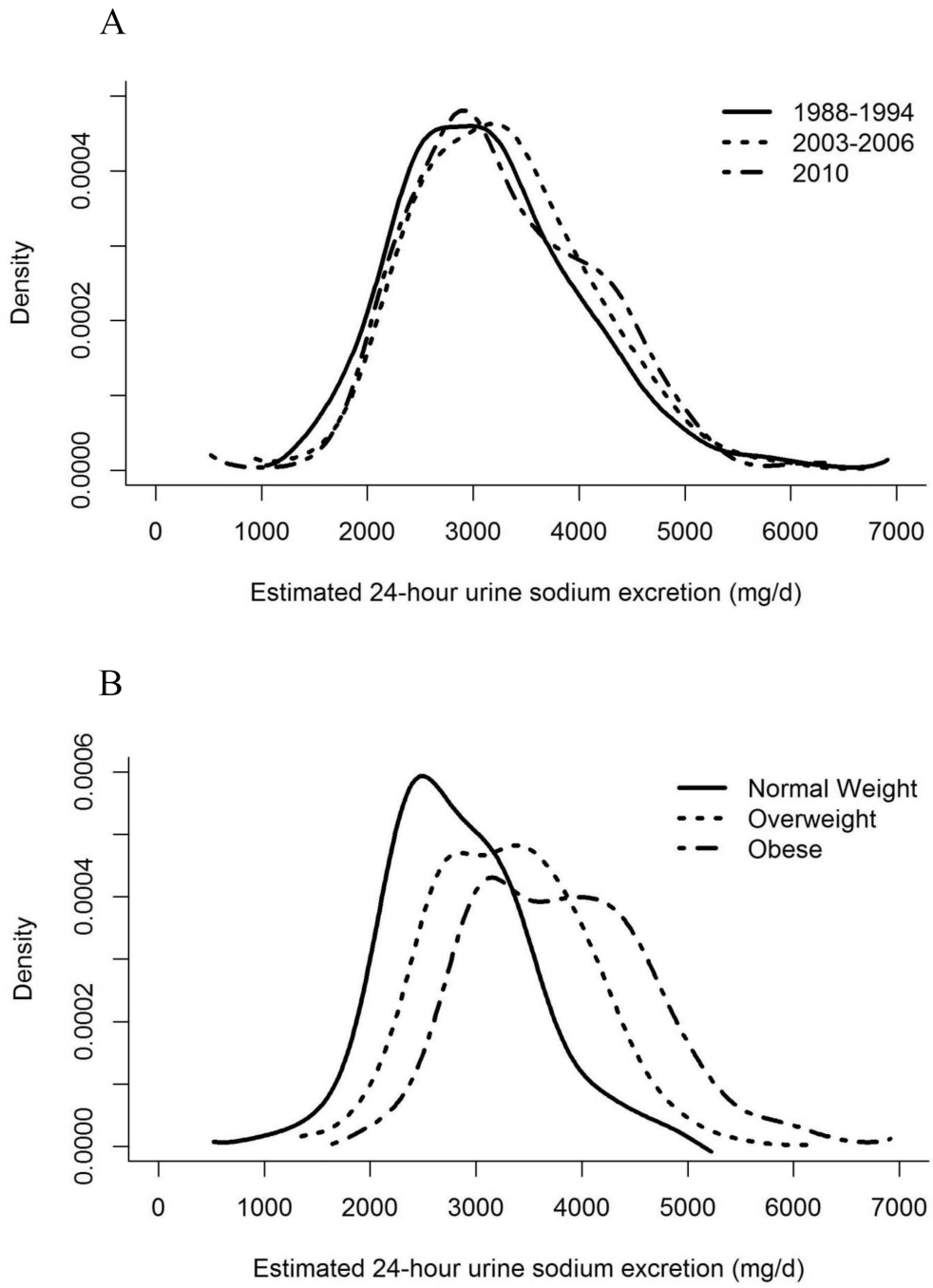

Figure 1.

Smoothed frequency distribution curves of estimated 24-h urine sodium excretion for U.S. adults 20–59 y of age by survey period (A) and BMI category (B), NHANES 1988–2010. To optimize resources, we randomly sampled NHANES participants 20–59 y of age for urine sodium analysis based on blood pressure and sodium intake. The 1988–1994 urine samples were a convenience sample of 2550 NHANES examinees of which we selected 1249; for NHANES 2003–2006, we selected 1241 participants from a 1/3 urine random

subsample (1 excluded due to extreme BMI, 5 excluded due to missing BMI); for NHANES 2010, we included data from 525 persons from a 1/3 urine random subsample.

Figure 2.

Mean estimated 24-h urine sodium excretion by sodium intake quartiles for U.S. adults 20–59 y of age by survey period, NHANES 1988–2010.

Sodium intake quartiles (Q1: <2989; Q2: 2989–<3663; Q3: 3663–<4517; Q4: ≥4517) have been determined by using the best linear unbiased predictor values. Error bars represent 95% CI. To optimize resources, we randomly sampled NHANES participants 20–59 y of age for urine sodium analysis based on blood pressure and sodium intake. The 1988–1994 urine samples were a convenience sample of 2550 NHANES examinees of which we selected 1249; for NHANES 2003–2006, we selected 1241 participants from a 1/3 urine random subsample (1 excluded due to extreme BMI, 5 excluded due to missing BMI); for NHANES 2010, we included data from 525 persons from a 1/3 urine random subsample. Sample sizes for sodium intake: 1988–1994, n = 1249 (Q1: 346, Q2: 338, Q3: 333, Q4: 232); 2003–2006, n = 1235 (Q1: 309, Q2: 295, Q3: 339, Q4: 292); 2010, n = 507 (Q1: 121, Q2: 172, Q3: 124, Q4: 90).

Table 1

Demographic and health characteristics of U.S. adults aged 20–59 y, NHANES 1988–2010[1,2]

	1988–1994		2003–2006		2010		*P* value[3]
	n	%	*n*	%	*n*	%	
Age group							0.020
20–39 y	713	59.9 ± 2.2	611	52.4 ± 1.8	285	52.8 ± 2.6	
40–59 y	536	40.1 ± 2.2	624	47.6 ± 1.8	240	47.2 ± 2.6	
Sex							0.29
Men	645	52.5 ± 2.3	725	53.3 ± 1.8	258	48.3 ± 2.7	
Women	604	47.5 ± 2.3	510	46.7 ± 1.8	267	51.7 ± 2.7	
Race-ethnicity							<0.0001
Mexican-American	330	6.3 ± 0.4	240	10.1 ± 0.7	90	11.7 ± 1.2	
Non-Hispanic black	424	12.6 ± 0.8	287	12.9 ± 0.9	93	13.1 ± 1.3	
Non-Hispanic white	446	81.1 ± 1.0	600	77.0 ± 1.2	235	75.2 ± 1.8	
BMI[4]							0.002
Normal weight	457	44.9 ± 2.3	366	36.5 ± 1.8	164	34.6 ± 2.5	
Overweight	413	30.7 ± 2.1	418	31.0 ± 1.6	181	32.7 ± 2.5	
Obese	356	21.4 ± 1.7	431	30.1 ± 1.6	173	31.0 ± 2.4	
Blood pressure[5]							<0.001
Normal	507	58.3 ± 2.2	431	52.3 ± 1.8	304	60.1 ± 2.6	
Prehypertension	504	31.1 ± 1.9	419	35.6 ± 1.7	162	33.6 ± 2.6	
Hypertension	195	10.5 ± 1.1	385	12.1 ± 0.7	43	6.2 ± 1.2	

[1] Values represent unweighted sample size *n* and weighted percentages ± SEM. DBP, diastolic blood pressure; SBP, systolic blood pressure.

[2] To optimize resources, we randomly sampled NHANES participants 20–59 y of age for urine sodium analysis based on blood pressure and sodium intake. The 1988–1994 urine samples were a convenience sample of 2550 NHANES examinees of which we selected 1249; for NHANES 2003–2006, we selected 1241 participants from a 1/3 urine random subsample (1 excluded due to extreme BMI, 5 excluded due to missing BMI); for NHANES 2010, we included data from 525 persons from a 1/3 urine random subsample.

[3] *P* value based on *Chi*-square test of independence

[4] BMI categories (kg/m^2): normal (18.5–<25), overweight (25–<30), obese (≥30)

[5] Blood pressure categories (mm Hg): normal (SBP <120, DBP <80), prehypertension (SBP 120–139 or DBP 80–89), hypertension (SBP ≥140 or DBP ≥90)

Table 2

Estimated 24-h urine sodium excretion in U.S. adults aged 20–59 y by demographic and health characteristics, NHANES 1988–2010[1,2]

	1988–1994	2003–2006	2010	P_{trend} value[3]
	mg/d	*mg/d*	*mg/d*	
All groups	3160 ± 38.4	3290 ± 29.4	3290 ± 44.4	0.022
Age group				
20–39 y	3130 ± 52.6	3240 ± 38.4	3320 ± 57.9	0.017
40–59 y	3200 ± 54.9	3350 ± 44.4	3250 ± 67.9	0.54
P value[4]	0.40	0.06	0.48	
Sex				
Men	3580 ± 50.7	3720 ± 34.7	3740 ± 57.6	0.032
Women	2690 ± 35.5	2800 ± 32.1	2860 ± 47.0	0.003
P value[4]	<0.001	<0.001	<0.001	
Race-ethnicity				
Mexican American	3440 ± 49.3	3530 ± 58.0	3410 ± 82.8	0.65
Non-Hispanic black	3260 ± 49.6	3400 ± 61.9	3470 ± 105	0.06
Non-Hispanic white	3120 ± 48.8	3230 ± 37.8	3240 ± 63.6	0.10
P value[4]	0.012	0.001	0.051	
BMI[5]				
Normal weight	2830 ± 45.3	2830 ± 42.4	2900 ± 60.7	0.44
Overweight	3330 ± 65.6	3380 ± 40.1	3180 ± 64.1	0.13
Obese	3730 ± 83.3	3820 ± 49.1	3890 ± 70.1	0.15
P value[4]	<0.001	<0.001	<0.001	
Blood pressure[6]				
Normal	2900 ± 51.0	3090 ± 41.6	3070 ± 50.9	0.014
Prehypertension	3470 ± 57.6	3480 ± 46.9	3580 ± 78.2	0.26
Hypertension	3640 ± 97.4	3610 ± 51.7	3780 ± 186	0.60
P value[4]	<0.001	<0.001	<0.001	

[1] Values are crude mean estimates ± SEMs (*n* are the same as in table 1). DBP, diastolic blood pressure; SBP, systolic blood pressure.

[2] To optimize resources, we randomly sampled NHANES participants 20–59 y of age for urine sodium analysis based on blood pressure and sodium intake. The 1988–1994 urine samples were a convenience sample of 2550 NHANES examinees of which we selected 1249; for NHANES 2003–2006, we selected 1241 participants from a 1/3 urine random subsample (1 excluded due to extreme BMI, 5 excluded due to missing BMI); for NHANES 2010, we included data from 525 persons from a 1/3 urine random subsample.

[3] *P* value based on test for linear trend using Satterthwaite adjusted F test

[4] *P* value based on Satterthwaite adjusted F test

[5] BMI categories (kg/m^2): normal (18.5–<25), overweight (25–<30), obese (≥30)

[6] Blood pressure categories (mm Hg): normal (SBP <120, DBP <80), prehypertension (SBP 120–139 or DBP 80–89), hypertension (SBP ≥140 or DBP ≥90)

Table 3

Dietary sodium intake in US adults aged 20–59 y by demographic and health characteristics, NHANES 1988–2010[1,2]

	1988–1994	2003–2006	2010	P_{trend} value[3]
	mg/d	*mg/d*	*mg/d*	
All groups	3280 ± 83.3	3270 ± 68.2	3400 ± 87.6	0.34
Age group				
20–39 y	3340 ± 117	3390 ± 101	3490 ± 124	0.39
40–59 y	3190 ± 114	3140 ± 92.3	3300 ± 125	0.51
P value[4]	0.37	0.07	0.30	
Sex				
Men	3950 ± 121	4030 ± 90.2	3940 ± 153	0.98
Women	2670 ± 99	2580 ± 79.1	2970 ± 92.4	0.037
P value[4]	<0.001	<0.001	<0.001	
Race-ethnicity				
Mexican American	3000 ± 118	3130 ± 127	3060 ± 161	0.83
Non-Hispanic black	3270 ± 114	2890 ± 133	3110 ± 179	0.33
Non-Hispanic white	3320 ± 105	3370 ± 91.0	3470 ± 122	0.37
P value[4]	0.44	0.039	0.054	
BMI[5]				
Normal weight	3330 ± 120	3150 ± 117	3140 ± 136	0.27
Overweight	3380 ± 171	3430 ± 107	3490 ± 145	0.64
Obese	3060 ± 165	3370 ± 128	3640 ± 184	0.018
P value[4]	0.54	0.10	0.06	
Blood pressure[6]				
Normal	3200 ± 122	3220 ± 103	3120 ± 94.7	0.63
Prehypertension	3360 ± 128	3350 ± 110	3930 ± 180	0.011
Hypertension	3530 ± 194	3270 ± 110	3320 ± 399	0.49
P value[4]	0.33	0.57	0.001	

[1] Values are crude geometric mean estimates ± SEMs [*n* are the same as in table 1 for 1988–1994 and 2003–2006; slightly lower *n* for 2010: 607 (all groups), 298 (20–39 y), 309 (40–59 y), 293 (males), 314 (females), 103 (Mexican Americans), 114 (non-Hispanic blacks), 276 (non-Hispanic whites), 170 (normal weight), 197 (overweight), and 233 (obese)]. DBP, diastolic blood pressure; SBP, systolic blood pressure.

[2] To optimize resources, we randomly sampled NHANES participants 20–59 y of age for urine sodium analysis based on blood pressure and sodium intake. The 1988–1994 urine samples were a convenience sample of 2550 NHANES examinees of which we selected 1249; for NHANES 2003–2006, we selected 1241 participants from a 1/3 urine random subsample (1 excluded due to extreme BMI, 5 excluded due to missing BMI); for NHANES 2010, we included data from 525 persons from a 1/3 urine random subsample.

[3] *P* value based on test for linear trend using Satterthwaite adjusted F test

[4] *P* value based on Satterthwaite adjusted F test

[5] BMI categories (kg/m^2): normal (18.5–<25), overweight (25–<30), obese (≥30)

[6] Blood pressure categories (mm Hg): normal (SBP <120, DBP <80), prehypertension (SBP 120–139 or DBP 80–89), hypertension (SBP ≥140 or DBP ≥90)

Table 4

Model adjusted means for estimated 24-h urine sodium excretion and dietary sodium intake in U.S. adults 20–59 y of age by demographic and health characteristics, NHANES 1988–2010[1,2]

	Estimated 24hUNa excretion		Dietary sodium intake	
	Model 1	Model 2	Model 1	Model 2
	mg/d	*mg/d*	*mg/d*	*mg/d*
Survey period				
1988–1994	3190 (3130–3240)	3230 (3180–3280)	3200 (3070–3340)	3210 (3080–3350)
2003–2006	3260 (3230–3290)	3260 (3230–3280)	3300 (3220–3390)	3300 (3220–3390)
2010	3330 (3270–3390)	3280 (3230–3330)	3410 (3260–3560)	3400 (3260–3550)
P_{trend} value[3]	0.004	0.22	0.07	0.10
Age group				
20–39 y	3210 (3170–3260)	3250 (3210–3290)	3400 (3280–3520)	3400 (3280–3530)
40–59 y	3310 (3260–3360)	3270 (3230–3310)	3190 (3070–3300)	3180 (3070–3300)
P value[4]	0.004	0.52	0.013	0.009
Sex				
Men	3670 (3640–3740)	3670 (3630–3720)	3990 (3870–4120)	4000 (3860–4120)
Women	2790 (2750–2830)	2810 (2770–2840)	2680 (2580–2790)	2690 (2590–2800)
P value[4]	<0.001	<0.001	<0.001	<0.001
Race-ethnicity				
Mexican American	3460 (3390–3530)	3360 (3300–3420)	3010 (2850–3170)	2990 (2830–3160)
Non-Hispanic black	3390 (3320–3460)	3300 (3240–3360)	3030 (2860–3200)	3010 (2850–3180)
Non-Hispanic white	3200 (3160–3240)	3230 (3190–3260)	3390 (3280–3500)	3390 (3280–3500)
P value[4]	<0.001	0.001	0.001	0.001
BMI[5]				
Normal weight	n/a	2910 (2860–2950)	n/a	3240 (3110–3380)
Overweight	n/a	3220 (3170–3270)	n/a	3290 (3160–3430)
Obese	n/a	3830 (3770–3880)	n/a	3410 (3240–3580)
P value[4]		<0.001		0.44

[1] Values are model-adjusted means for estimated 24hUNa excretion (95% CI) and geometric means for dietary sodium intake (95% CI); the model-adjusted least square mean or geometric mean has been derived from a multiple linear regression model containing age, sex, race-ethnicity, and survey period (model 1) or age, sex, race-ethnicity, BMI, and survey period (model 2)

[2] To optimize resources, we randomly sampled NHANES participants 20–59 y of age for urine sodium analysis based on blood pressure and sodium intake. The 1988–1994 urine samples were a convenience sample of 2550 NHANES examinees of which we selected 1249; for NHANES 2003–2006, we selected 1241 participants from a 1/3 urine random subsample (1 excluded due to extreme BMI, 5 excluded due to missing BMI); for NHANES 2010, we included data from 525 persons from a 1/3 urine random subsample.

[3] *P* value based on test for linear trend using Satterthwaite adjusted F test

[4] *P* value based on Satterthwaite adjusted F test

[5] BMI categories (kg/m^2): normal (18.5–<25), overweight (25–<30), obese (≥30)